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# Vacuum Chamber and Adaptors for Shearography and Holography (5-32902)

Final Technical Report for Period
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Study methods to excite aeorspace components using vacuum to induce deformations which will be measured by shearography, holography, and image correlation.

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# PREFACE

This technical report was prepared by the staff of the Research Institute, The University of Alabama in Huntsville. The purpose of this report is to provide documentation of the work performed and the results obtained under the Delivery Order 31 of Marshall Space Flight Center (MSFC) Contract No. NAS8-38609. Mr. James R. Clark was the Principal Investigator and Mr. Charles M. Horton was the Co-Principal Investigator for this nine month level of effort. Dr. Samuel S. Russell of the NDE Branch, EH-13, of MSFC/NASA provided technical support and direction. Mr. Thomas J. King of Pratt & Whitney provided support in the mechanics of Holography/Shearography Systems.

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official NASA position, policy, or decision unless so designated by other official documentation.

I have reviewed this report, dated 25 Jan. 93 and the report contains no classified information.

James R. Clark
Principal Investigator

Charles M. Horton
Co-Principal Investigator

Approval:

Gary A. Maddux
Research Institute

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## 1.0 INTRODUCTION

Electronic Holographic and Shearographic NDE are optical inspection methods that can detect sub-surface flaws such as unbonds and delaminations in bonded, laminated, composite or coated structures. The two methods detect flaws by displaying, in real-time on a video monitor, the surface deformation (strain) that results from the structure being stressed by either a steady state load (pressure, vacuum, or mechanical) or a dynamic load (temperature or acoustic vibration). Since the structure or coating is locally weak where a sub-surface flaw exists, Holographic or Shearographic NDE will detect an area of high surface deformation (strain) when a load is applied.

## 2.0 ACTIVITIES

NASA and UAH collaborated in a joint study to consider methods of vacuum exciting structures to induce deformations to be measured by shearography, holography, and image correlation. A Pratt & Whitney (P&W) Electronic Holography/Shearography Inspection System (EH/SIS) was used by the NDE Branch, EH-13, of NASA/MSFC in this study. The system uses a ND:YAG laser an a frequency doubler to produce a constant wave 532nm green light source for illumination of the test object. Light is reflected from the object and acquired by a standard CCD Video Camera, equipped with special optics, for image processing. Images may be acquired through any optically clear non-distorting medium.

## 3.0 CONCEPTUAL DESIGN

The Bell Jar is the most commonly recognized device for a controlled vacuum environment in scientific experiments. A cylindrical glass vessel would be the ideal choice as a vacuum chamber because the test object could be viewed from any direction without opening the chamber to rotate the piece. Due to the limitations of the Bell Jars size and the optical distortion caused by the curvature of the vessel walls another design was required.

## 4.0 PROTOTYPE DEVELOPMENT AND OPERATION

The design chosen was a hexagon shaped vacuum chamber made of six flat acrylic panels. The flat optically clear panels would provide distortion free viewing from all sides. The vacuum excitation chamber consists of three major components; a lid, chamber body, and base plate. (Figure 1.) The vacuum chamber design was scaled and constructed to hold larger size specimens than available vacuum chambers. The chamber accommodates a specimen of 1 meter in diameter (max). The chamber body was constructed of 22" x 48" x 1" acrylic panels solvent welded to form one continuous hexagon tube, open at both ends. The top and bottom edges are fitted with molded continuous neoprene rubber channel gaskets to insure a vacuum seal. The removable lid consisted of a flat hexagon of 1 1/2" acrylic material. The oversized lid rests on the channel gasket that covers the top of

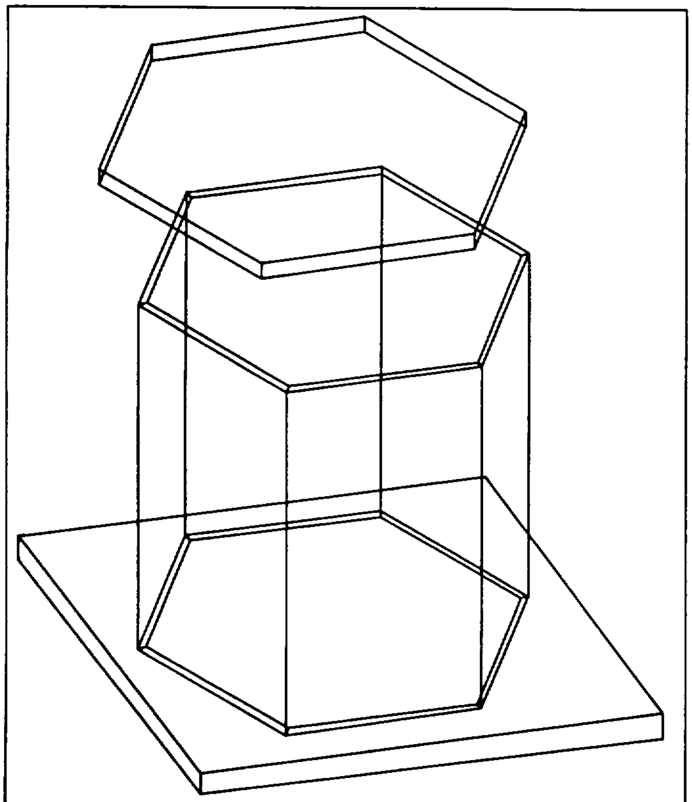


Figure 1.
Lid, Chamber Body, and Base Plate.

the vacuum chamber, closing the open end. The channel gasket that covers the bottom of the chamber rests upon a reinforced 48" x 48" x 1 1/2" aluminum base plate. The chamber has four handles so that it may be easily moved from the isolation table to its storage cart. Care should be taken not to roll the channel gasket off the bottom edge of the chamber during movement. The chamber should be lifted clear of the base plate and not dragged when moved.

Because vacuum deformation of the base plate would cause significant movement of the test specimen, a false bottom was constructed of 1/2" plate aluminum to fit inside the test chamber. This hexagon shaped "table" fits easily inside the chamber with support legs at the perimeter. The flat plate of the table was drilled and tapped with 1/4"-20 SAE holes to allow for the installation of support members and fixtures for specimens under inspection. Any deflection that occurs during extreme vacuum conditions, is most significant in the middle of the base plate and less evident at the chamber walls. Because the table is supported along the perimeter of the chamber walls the "free floating" table dampens any movement due to vacuum deformation.

With the lid removed the chamber could be tilted on its edge for easy insertion and removal of the specimen table under the raised chamber edge. Easy access could also be gained for any small test objects that required inspected. (Figure 2.)

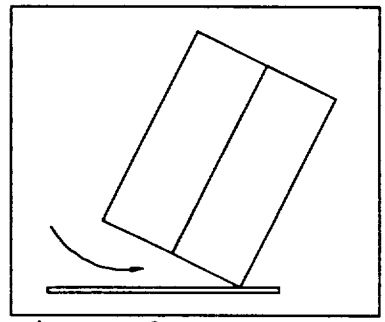


Figure 2.

An Industrial wet/dry vacuum head installed on a 55 gallon drum was used to provide a vacuum source to quickly reduce the pressure in the chamber. The vacuums 1 1/2" hose pipe is attached to the vacuum out gas ball cock by a quick release connector. The 3.5 HP two-stage bypass motor moves 110 CFM of air at the static pressure rate of 7.7in HG (3.8 PSIG). This volume enabled the chamber pressure to be reduced and held at 7.7in HG (3.8 PSIG) in 18 seconds. A convectional vacuum pump requires at least 10 times longer to achieve the same vacuum. Rapid changes in the internal pressures of the test specimen with respect to the chamber environment provides more possibility of movement in unbonded materials. Slower vacuum rates allow for the equalization of the internal pressure differentials which cause detectable movement. (Figure 3.)

Once the desired pressure had been reached the vacuum out gas ball cock is closed to maintain the desired pressure in the test chamber. A second gas ball cock is installed as a "waste gate". The waste gate is adjusted until the air flow entering the chamber equaled the air flow exiting the chamber. This "fine tuning" of the waste gate aids in establishing an equilibrium between atmosphere and the vacuum source when constant vacuum levels are required. The waste gate also allows pulsing of the vacuum level in the chamber. A needle valve is provided for precision control of air flows entering the chamber. In cases where heavier steady state loads are needed to stress a part, a 1/4" hose barb connector attached to the needle valve allows any conventional vacuum pump to be attached and further reduce the pressure in the chamber.

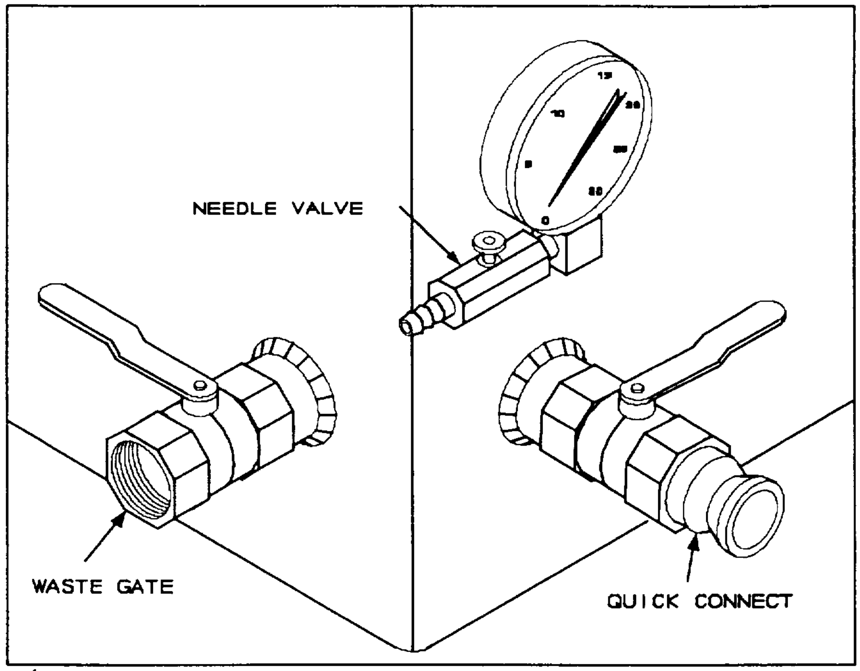


Figure 3.
Inlet/Outlet Valves

As a safety precaution a vacuum breaker has been installed on the chamber. The

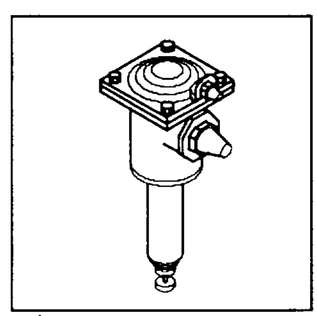


Figure 4.
Vacuum Breaker

vacuum breaker has been set at 13in. HG (6.4 PSIG). Once the vacuum inside the chamber reaches the preset level the breaker opens to the outside atmosphere and stabilizes the pressure in the chamber. (Figure 4.)

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

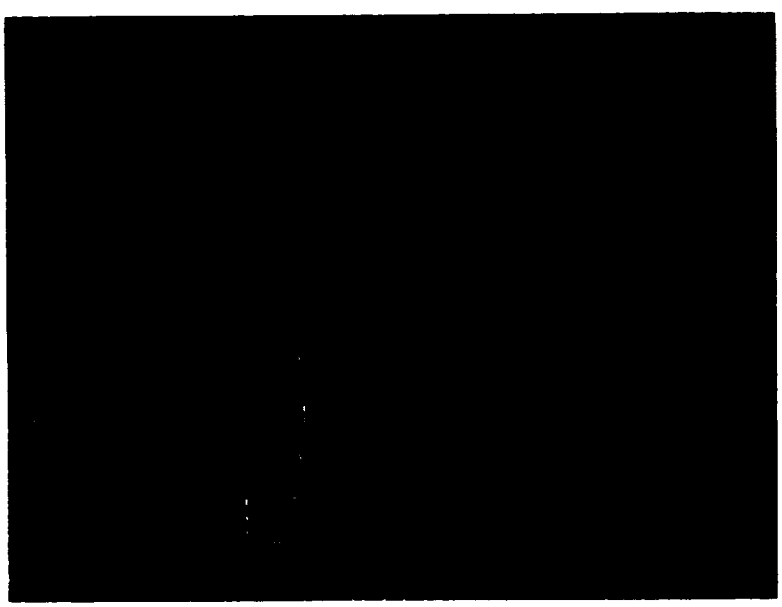
The vacuum excitation chamber has proven to be an excellent method for stressing aerospace components. The results achieved so far indicate that Holographic/Shearographic Optical NDE is a viable method for detecting surface deformations resulting from sub-surface flaws. Further evaluation would appear to be in order to validate this method as an acceptable means of NDE inspection.

# EXHIBIT A

## UNBONDED AREAS DETECTED BY SHEAROGRAPHY
## USING PRESSURE REDUCTION

Typical Shearographic Image

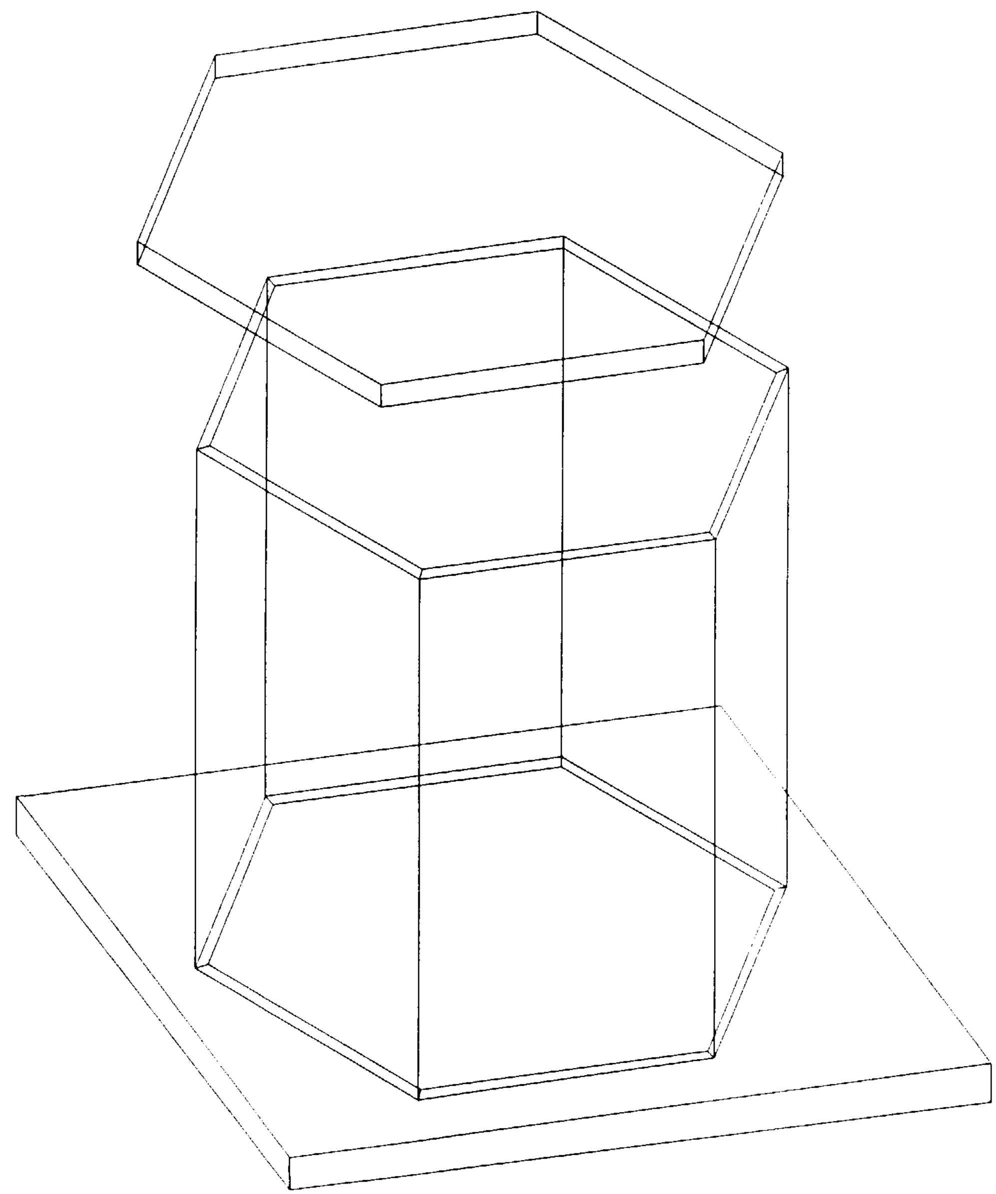
Pressure Reduction



Pressure Reduction

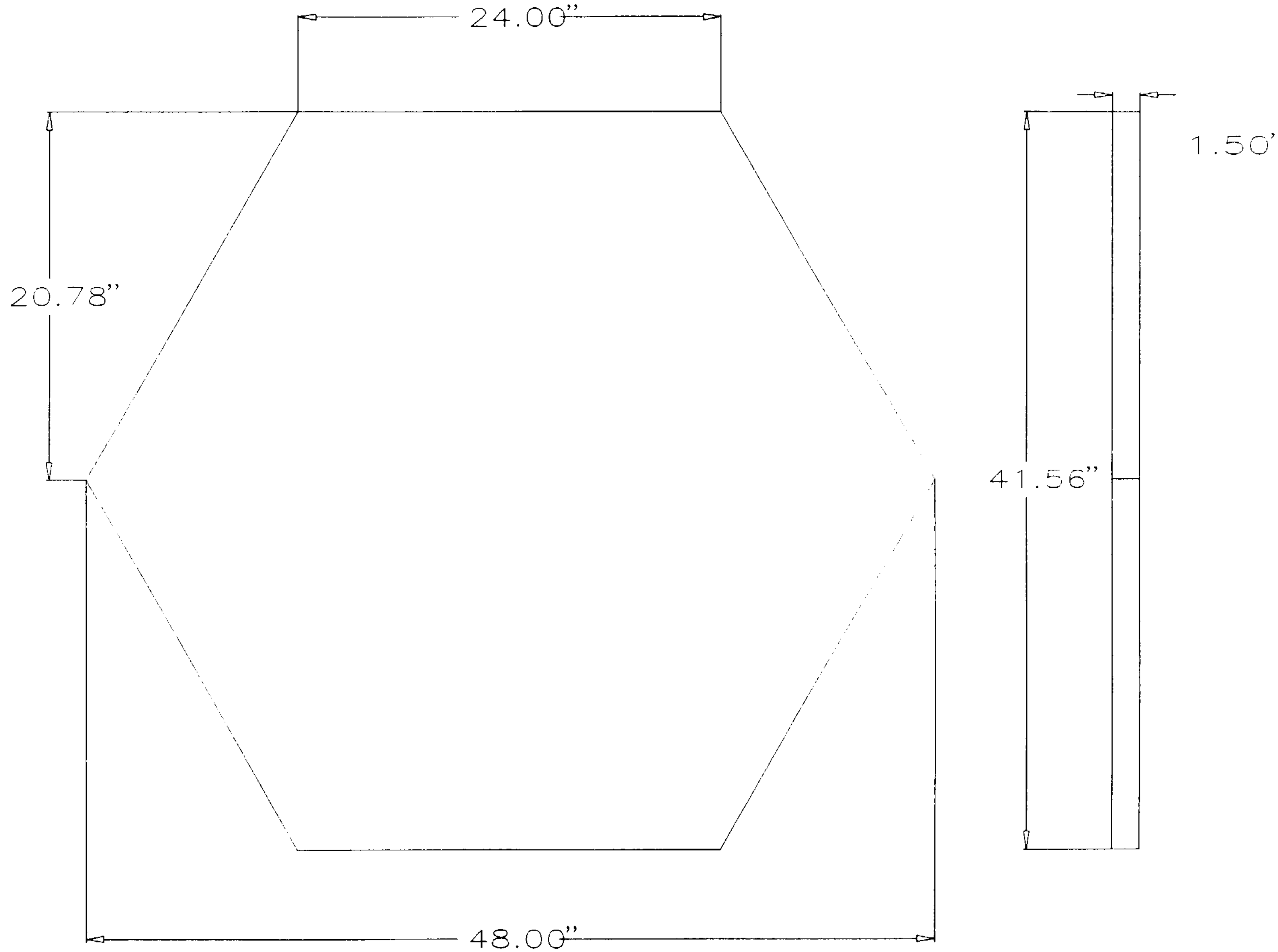
EXHIBIT B

VACUUM CHAMBER DESIGN DRAWINGS

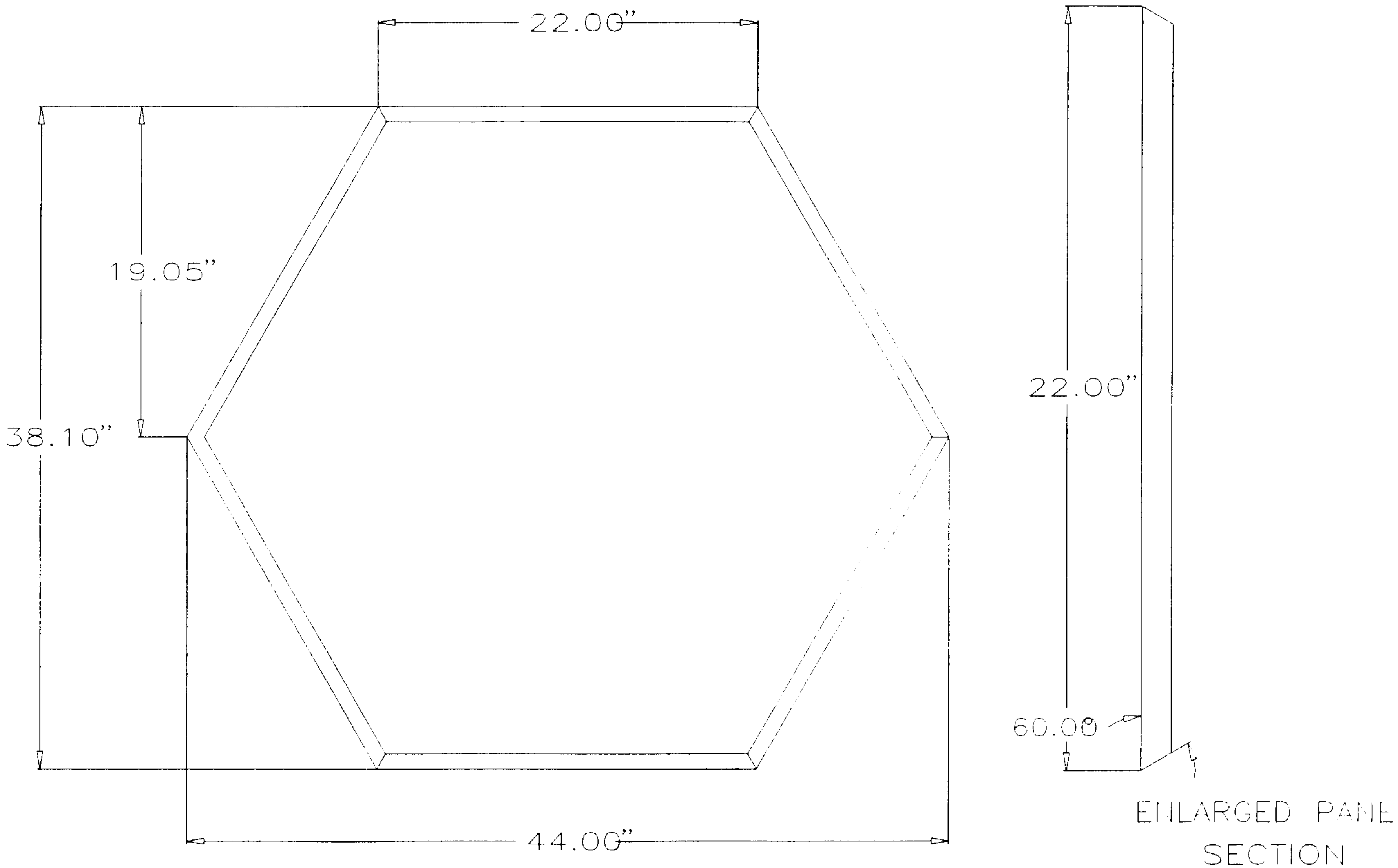


VACUUM EXCITATION CHAMBER
LID, CHAMBER BODY, AND BASE PLATE

COVER MADE OF 1 1/2" TK. MATERIAL

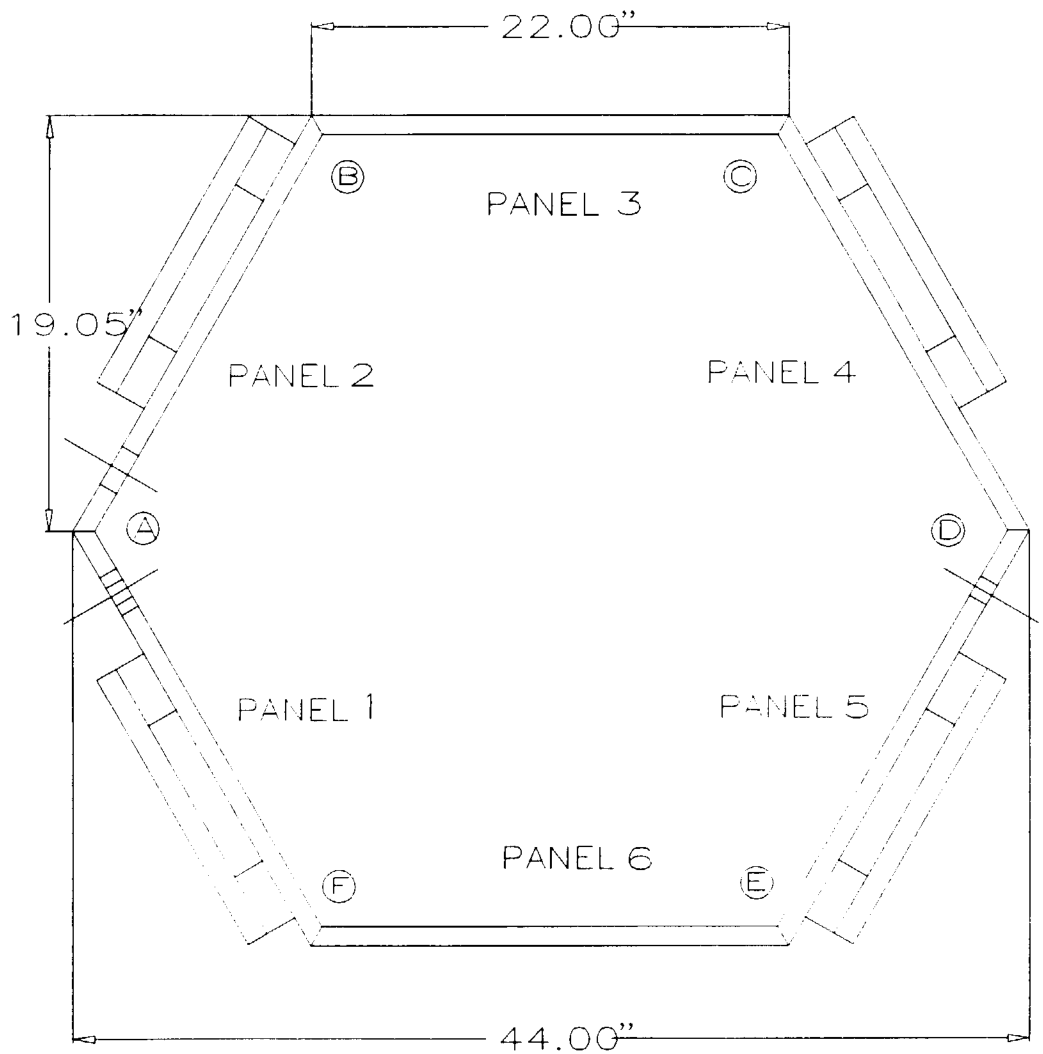



VACUUM EXCITATION CHAMBER LID

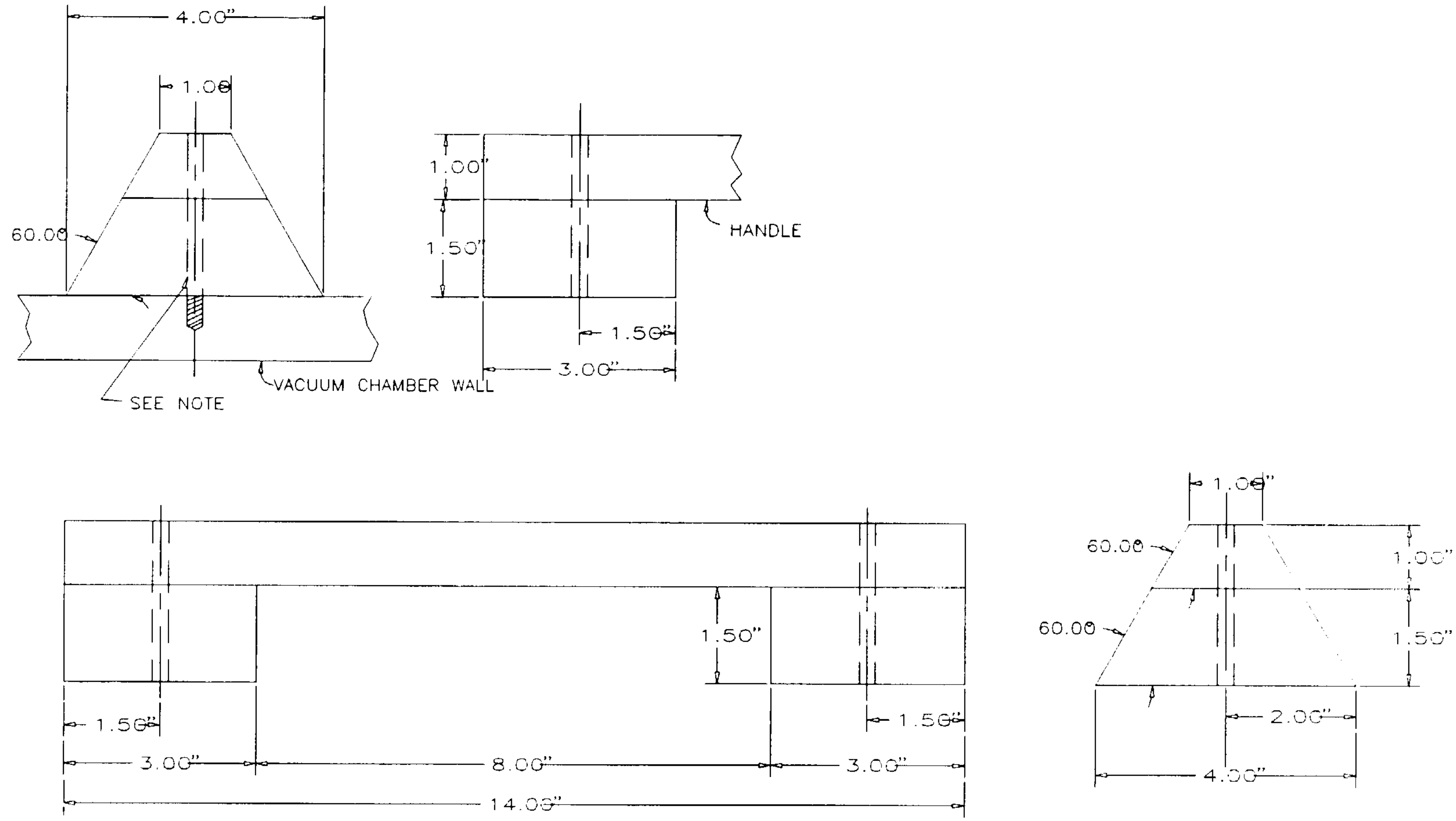



VACUUM EXCITATION CHAMBER FOOTPRINT
TOP VIEW

CHAMBER WITH HANDELS AND HOLES

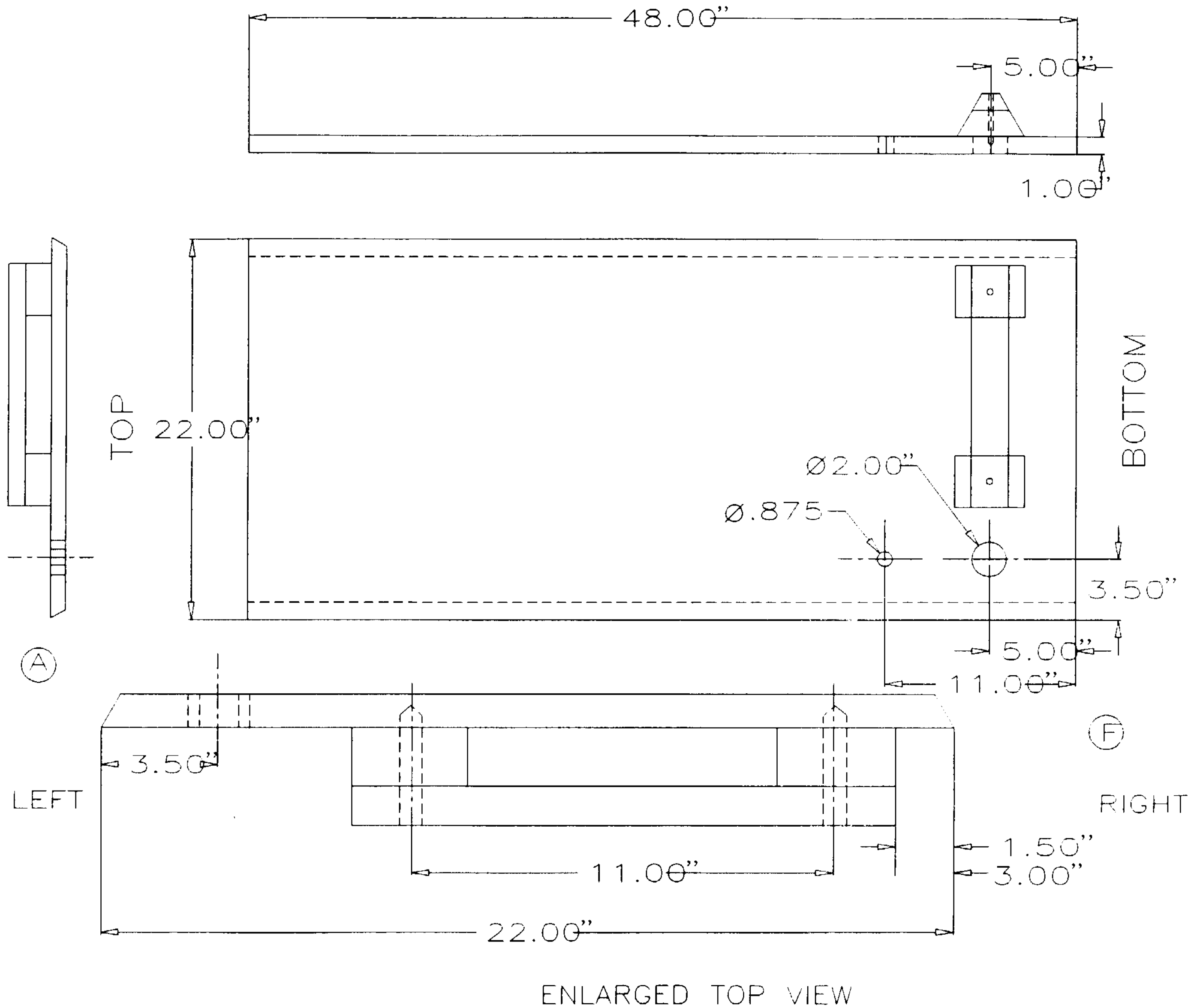



VACUUM EXCITATION CHAMBER PANEL LOCATIONS
TOP VIEW

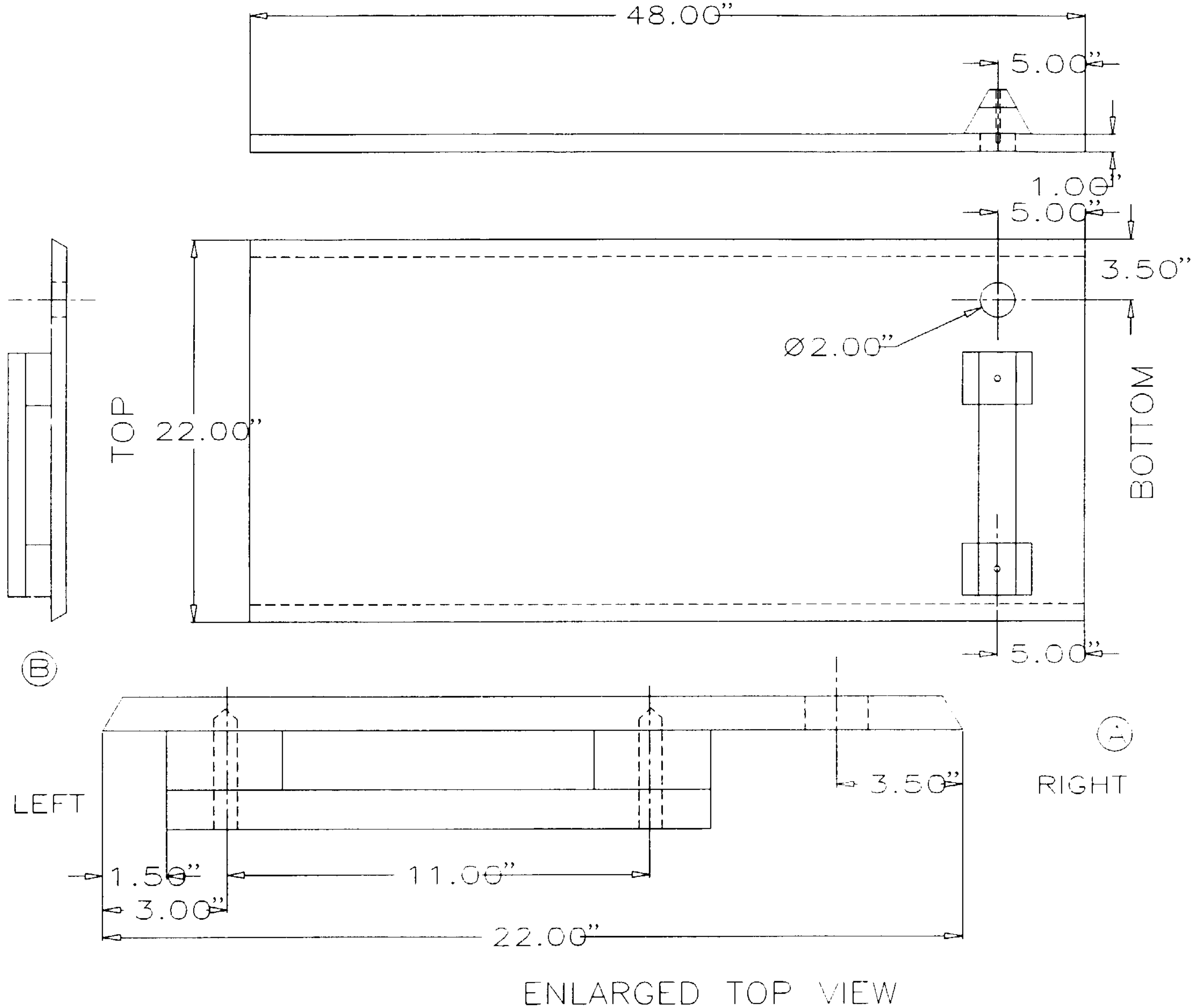



NOTE:HANDLES WILL BE GLUED AND BOLTED .
1/4"-20 X 3" BOLT OR FABRICATORS CHOICE.
TAPPED HOLE MUST NOT BREAK THROUGH TO INSIDE OF CHAMBER WALL.

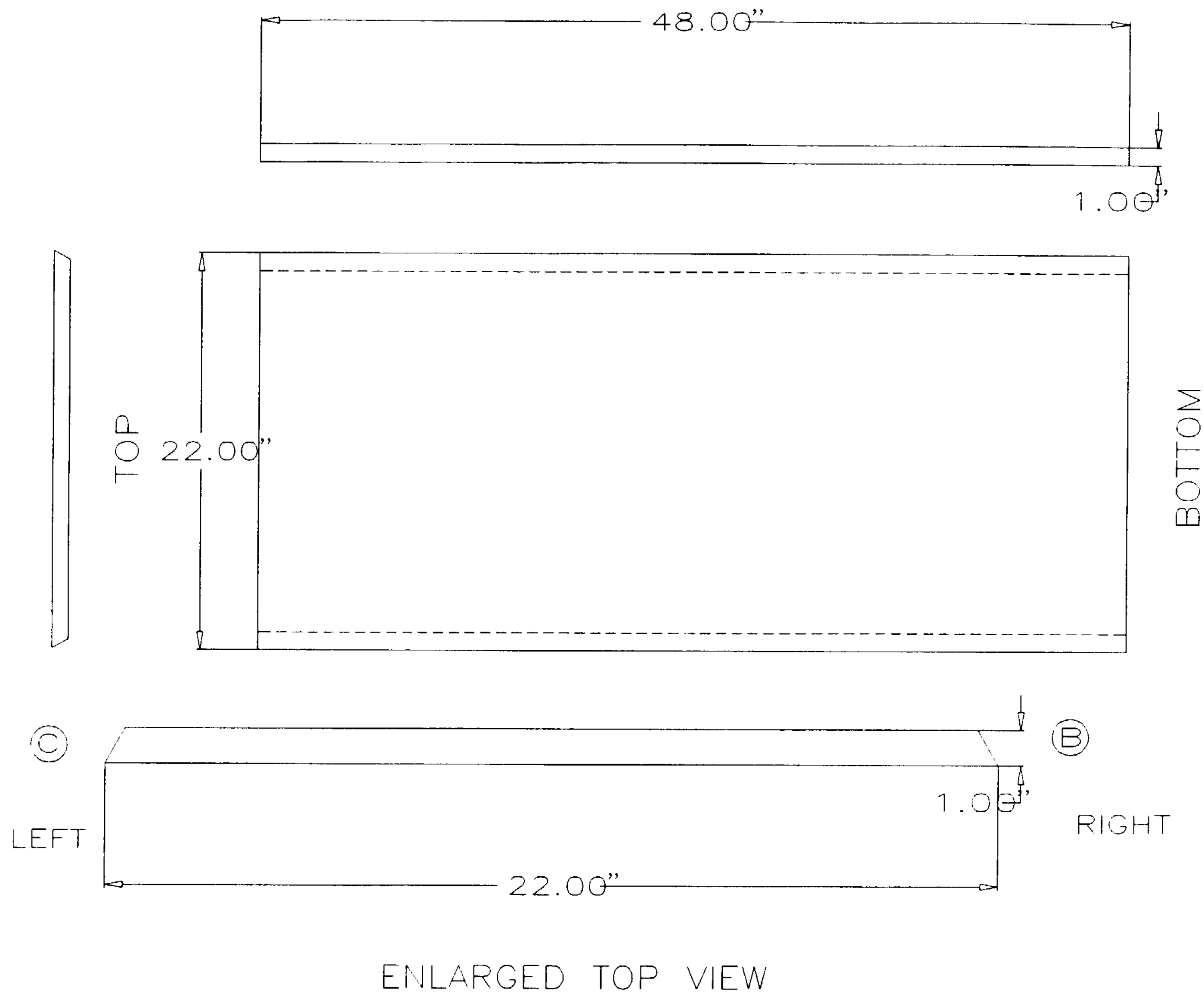
# VACUUM EXCITATION CHAMBER
# HANDLE CONSTRUCTION



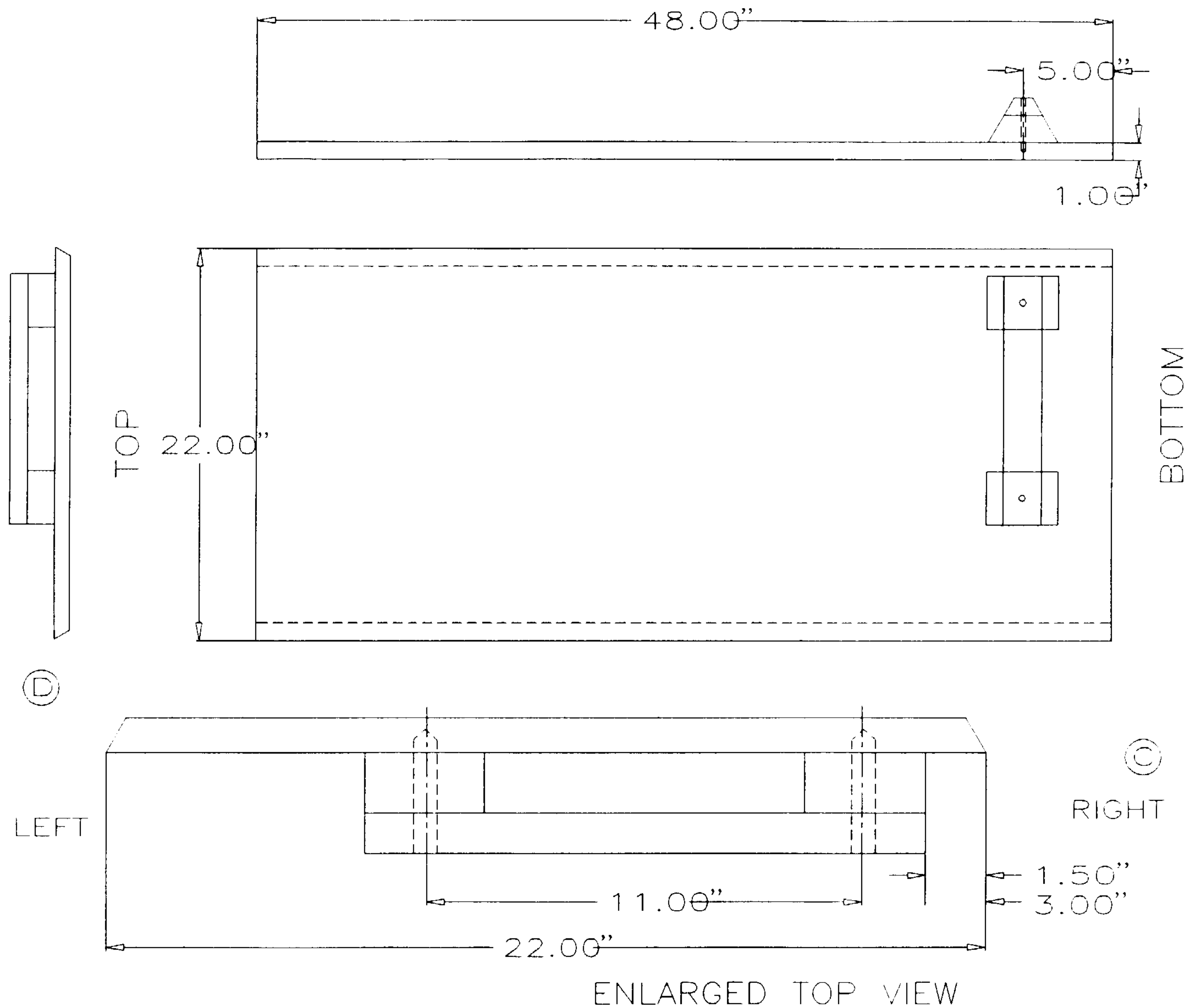

VACUUM EXCITATION CHAMBER
PANEL 1



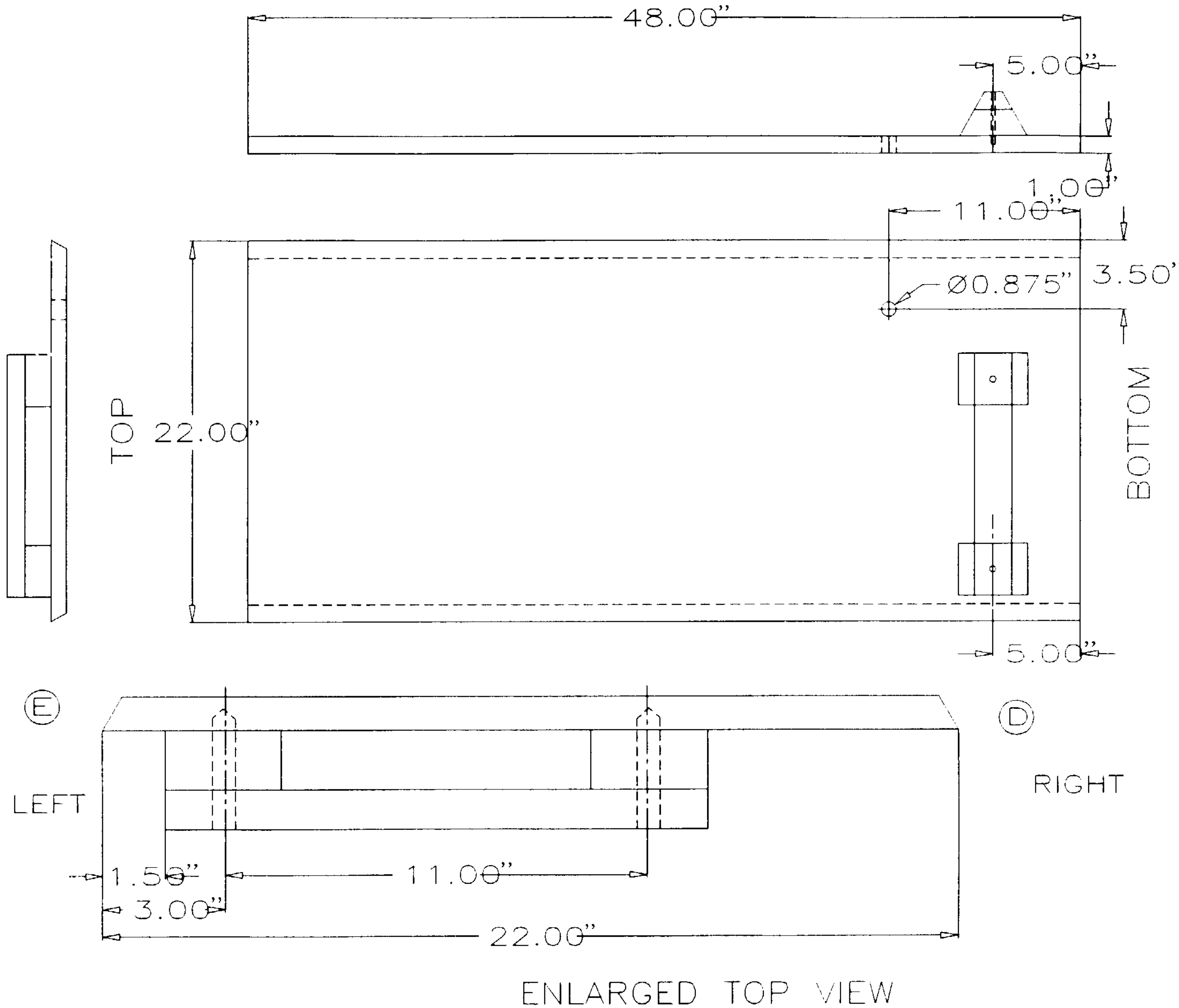

VACUUM EXCITATION CHAMBER
PANEL 2



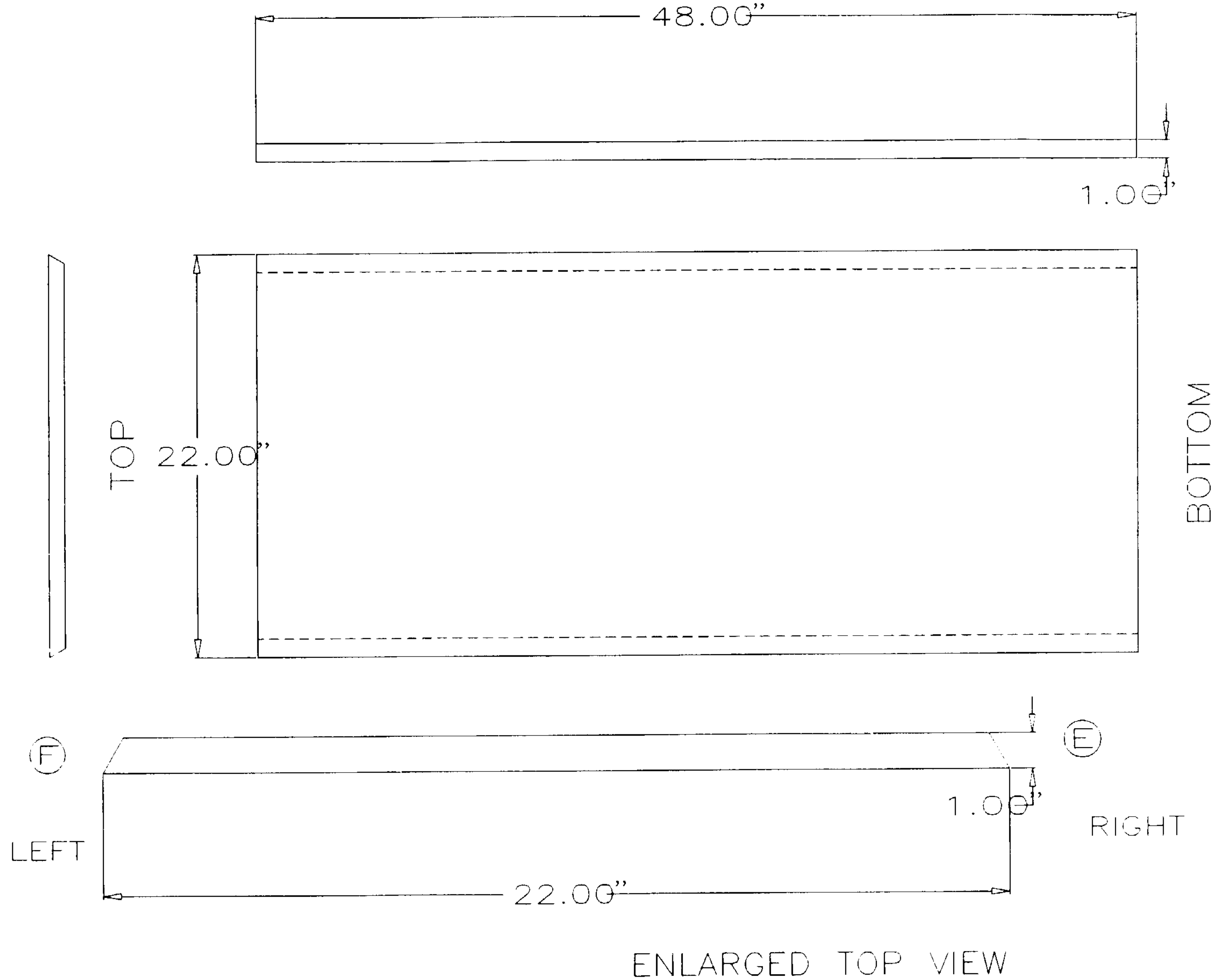

VACUUM EXCITATION CHAMBER
PANEL 3



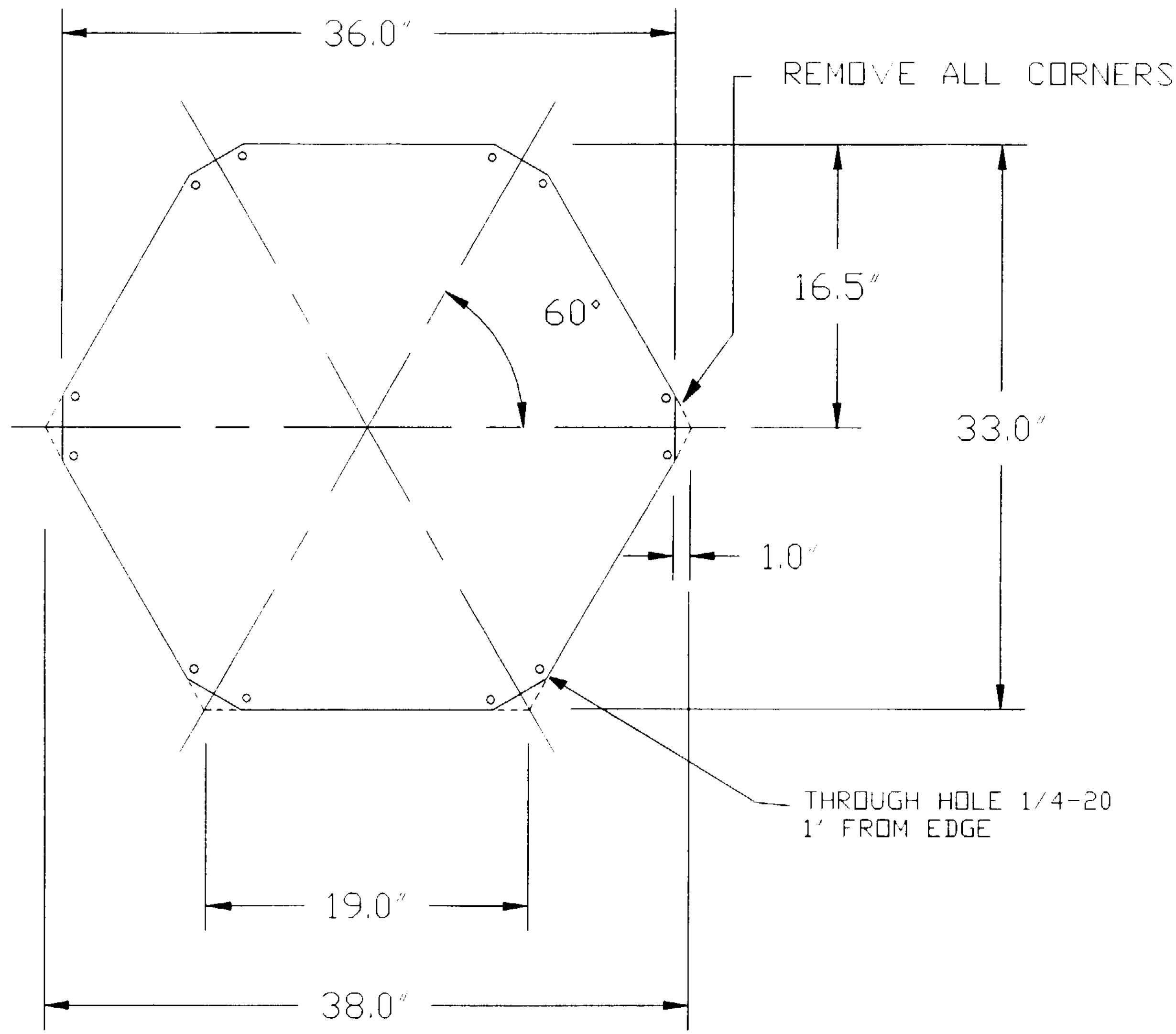

VACUUM EXCITATION CHAMBER
PANEL 4




VACUUM EXCITATION CHAMBER
PANEL 5

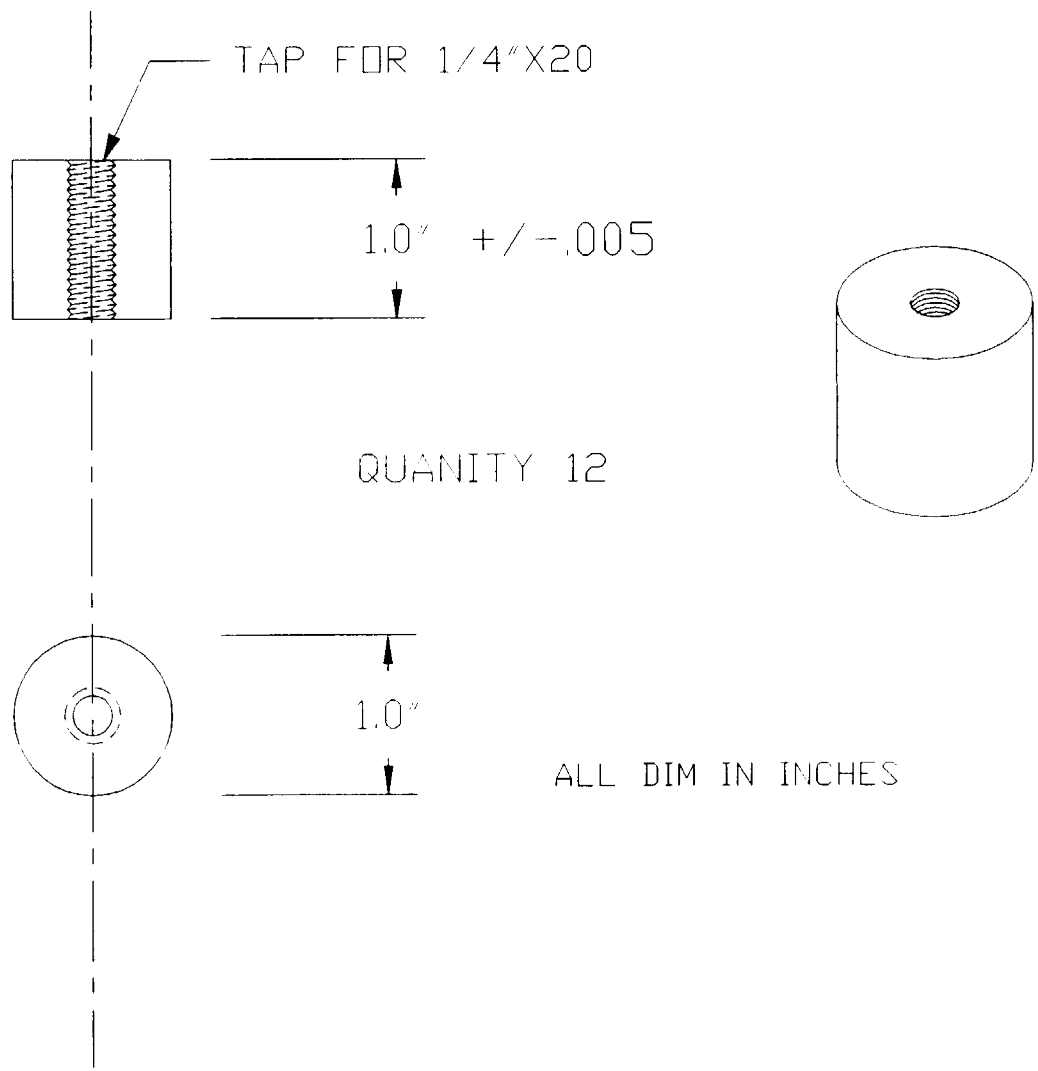



VACUUM EXCITATION CHAMBER
PANEL 6

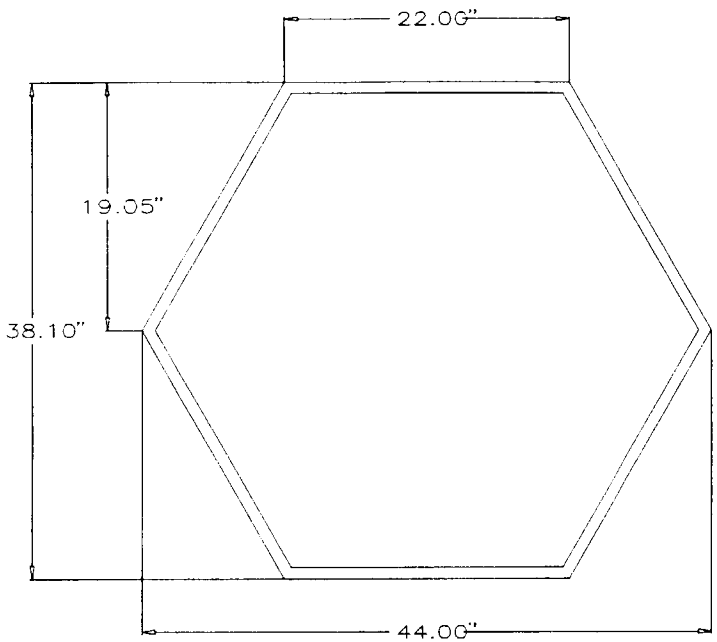



MATERIALS: 0.5" ALUM. PLATE

VACUUM EXCITATION CHAMBER
FLOATING BOTTOM

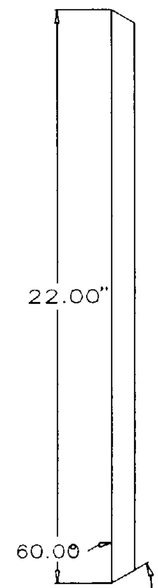



VACUUM EXCITATION CHAMBER
FLOATING BOTTOM LEGS

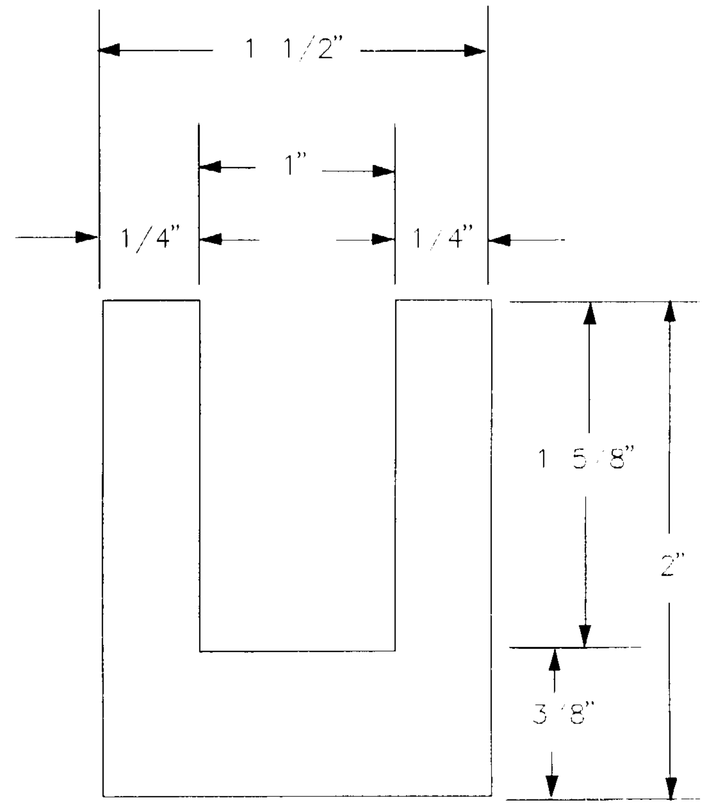



CHAMBER FOOTPRINT

11 FEET IN CIRCUMFERENCE




ENLARGED PANEL SECTION




ENLARGED CROSS SECTION OF CHANNEL GASKET

TOP CHANNEL GASKET 15 +/- DURO

BOTTOM CHANNEL GASKET 30 +/- DURO

GASKETS ARE MADE OF NEOPRENE RUBBER

# VACUUM EXCITATION CHAMBER CHANNEL GASKETS

# EXHIBIT C

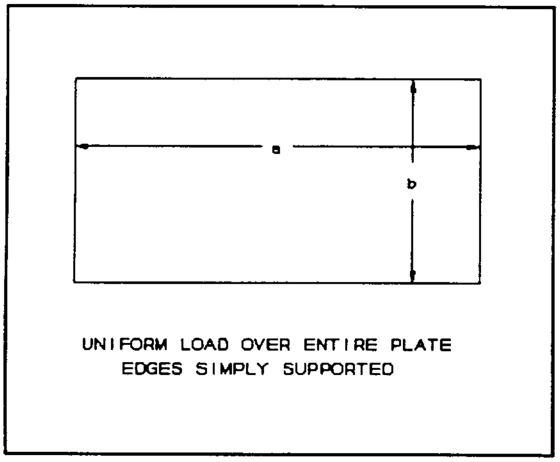
# VACUUM CHAMBER STRESS ANALYSIS

PROPERTIES OF CAST ACRYLIC SHEET

.250 INCHES THICK - ASTM TEST METHOD

| | |
|---|---|
| SPECIFIC GRAVITY (D792) ................ | 1.19 |
| TENSIL STRENGTH (D638) ................. | 10,000psi<br>(69MPA AT 4.2%) |
| ELASTIC MODULUS ........................ | 400,000psi<br>(2800 MDA) |
| FLEXURAL STRENGTH (D790) ............... | 16,500psi<br>(RUPTURE 114 MPA) |
| MODULUS OF ELASTICITY .................. | 475,000psi<br>(3300 MPA) |
| COMPRESSION STRENGTH (D695) ............ | 18,000psi<br>(YIELD 124 MPA) |
| MODULUS OF ELASTICITY .................. | 430,000psi |
| SHEAR STRENGTH (D732) .................. | 9,000psi |
| IMPACT STRENGTH (D256) .................<br>(IZOD MILLED NOTCH) | 0.4 lbs./in. of notch<br>(21.6j/m of notch) |
| ROCKWELL HARDNESS (D785) ............... | M94 |
| BARCOL HARDNESS (D2583) ................ | 49 |
| RESIDUAL SHRINKAGE .....................<br>(INTERNAL STRAIN) | 2% per 0.250 inch |
| OPTICAL CLEAR MATERIAL | |
| REFRACTIVE INDEX (D542) ................ | .025 - 1.49 |
| LIGHT TRANSMISSION (D1003) ............. | 92% |
| UV TRANSMISSION ........................ | 0 at 320nm |
| HAZE ................................... | LESS THAN 1% |
| THERMAL ................................ | 300deg.F - 350deg.F |
| WATER ABSORPTION ....................... | 24 hours - 73deg.F - 2% |

Stress loads for a single 22" x 48" x 1" vacuum chamber wall plate. Using the stress formulas for flat plates with straight boundaries and constant thickness the maximum safe load limits have been calculated. The tensile strength of acrylic is 10,000psi. With a safety factor of five the maximum safe psi load levels for a flat acrylic plate should not exceed 2,000psi.




$$\sigma = \frac{\beta \times b^2 \times q}{t^2}$$

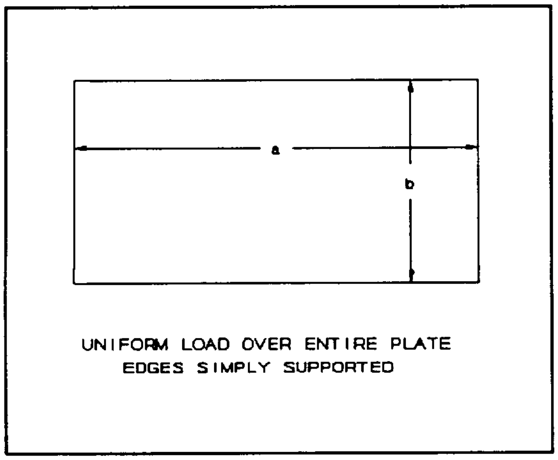
$a = 48''$ $\quad b = 22''$ $\quad \frac{a}{b} = 2.18$ $\quad \beta = 0.6102$ $\quad q = lbs\ per\ inch^2$

$$\sigma = \frac{0.6102 \times (22\,inch)^2}{(1\,inch)^2} = q \times 295.3\,psia$$

$$\sigma = q \times 295.3\,psia$$

For $q = 6.5 psia$ $\qquad \sigma = 1919.45 psia$

Stress loads for the 38" x 44" x 1 1/2" vacuum chamber lid. Using the stress formulas for flat plates with straight boundries and constant thickness, the maximum safe load limits have been calculated. The tensil strength of acrylic is 10,000psi. With a safety factor of five the maximum safe psi load levels for a flat acrylic plate should not exceed 2,000psi.




$$\sigma = \frac{\beta \times b^2 \times q}{t^2}$$

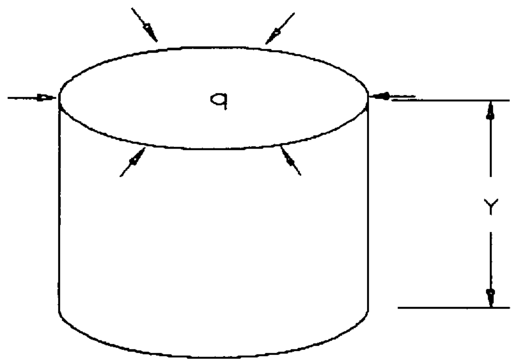
$a = 44''$ $\quad b = 38''$ $\quad \frac{a}{b} = 1.157$ $\quad \beta = 0.3762$ $\quad q = lbs\ per\ inch^2$

$$\sigma = \frac{0.3762 \times (38\,inch)^2}{(1.5\,inch)^2} = q \times 241.43\,psia$$

$$\sigma = q \times 241.43\,psia$$

$$For\ q = 6.5psia \qquad \sigma = 1569.33psia$$

Approximation of stresses for vacuum chamber using the formulas for membrane stresses and deformations in thin-walled vessels. These number represent a cylinder 44" in diameter with 1" thick walls. The tensile strength of acrylic is 10,000psi. With a safety factor of five the maximum safe load limits have been calculated and should not exceed 2,000psi.




UNIFORM RADIAL PRESSURE,
q = pounds per inch squared

$$\sigma = \frac{-q \times r}{t}$$

$t = wall\ thickness = 1''$

$q = lbs/inch^2$

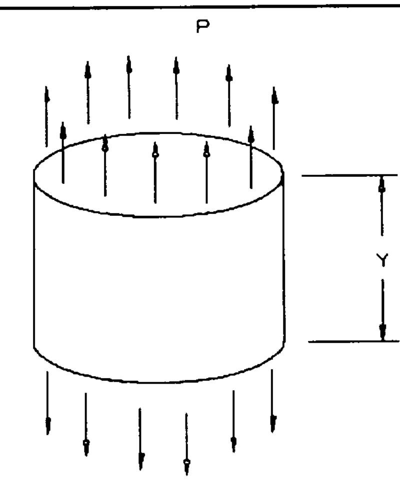
$r = radius = 22''$

$$\sigma = \frac{-1 \times 22''}{t}$$

$$\sigma = 1\,lb \times -22'' = -22\,psia$$

$$\sigma = 6.5\,lb \times -22'' = -143\,psia$$

Approximation of stresses for vacuum chamber using the formulas for membrane stresses and deformations in thin-walled vessels. These numbers represent a cylinder 44" in diameter with 1" walls. The tensile strength of acrylic is 10,000psi. With a safety factor of five the maximum safe load limits have been calculated and should not exceed 2,000psi.




UNIFORM AXIAL LOAD,

p = pounds per linear inch

$$\sigma = \frac{p}{t}$$

$t$ = *wall thickness* = 1″

$p$ = *lbs/linear inch*

$$cir = 2 \times \Pi \times radius = 2 \times 3.14 \times 22'' = 138.23''$$

$$\sigma = 1\,lb \times 138.23'' = 138.23\,psia$$

$$\sigma = 6.5\,lb \times 138.23'' = 898.49\,psia$$

# EXHIBIT D

# VACUUM CHAMBER PARTS LIST

PARTS LIST - VACUUM EXCITATION CHAMBER

1. VACUUM EXCITATION CHAMBER - 1" ACRYLIC PLATE
   (CHAMBER WEIGHT - 250 LBS.)
2. CHAMBER LID - 1 1/2" ACRYLIC PLATE
   (LID WEIGHT - 90 LBS.)
3. TOP EDGE GASKET ( NEOPRENE RUBBER 15 +/- 5 DURO )
4. BOTTOM EDGE GASKET ( NEOPRENE RUBBER 30 +/- 5 DURO )
5. VACUUM GAUGE, BOURDON TUBE TYPE, 4 1/2" DIAL, 1/4" PIPE SIZE
6. NEEDLE VALVE, 1/4" PIPE SIZE
7. 1/4" CLOSE NIPPLE, BRASS
8. 1/4" x 1/4" HOSE BARB, BRASS
9. 1/2" - 1/4" REDUCER, BRASS
10. 1/4" - 45DEG. ELBOW, BRASS
11. 1/8" MUFFLER/FILTER
12. 1/2" MUFFLER/FILTER
13. 1/4" TEE, BRASS
14. VACUUM BREAKER, ADJUSTABLE, 1/2" PIPE SIZE
15. 2 EA. 1 1/2" x 1/16" RUBBER WASHERS
16. 2 EA. 7/8" x 1/16" RUBBER WASHERS
17. 2 EA. 1 1/2" PVC ACID DRAINS
18. 2 EA. 1/2" BRASS DRAINS
19. 2 EA. 1 1/2" GAS BALL COCKS
20. INDUSTRIAL WET/DRY VACUUM HEAD ASSEMBLY
21. 55 GALLON FRH DRUM
22. DRUM DOLLY, 55 GALLON
23. 1 1/2" QUICK CONNECT COUPLER W/ HOSE CLAMPS

PARTS LIST CONT.

24. VACUUM CHAMBER STORAGE CART

25. 48" x 48" x 1 1/2" ALUMINUM BASE PLATE

    (BASE PLATE WEIGHT - 345 LBS.)

26. CHAMBER FALSE FLOOR, 1/2" PLATE ALUMINUM - HEXAGON SHAPE